Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

THE EFFECTS OF TRANSPLANTING LIMBS UPON THE FORMATION OF NERVE PLEXUSES AND THE DEVELOPMENT OF PERIPHERAL NEURONES

By S. R. Detwiler

Osborn Zoological Laboratory and Anatomical Laboratory, School of Medicine, Yale University

Communicated by R. G. Harrison, June 6, 1919

Previous experiments on the transplantation of limbs (Braus,[1] Banchi,[2] Gemelli[3] and Harrison[4]) have shown, with the exception of those of Banchi, that limbs placed in an abnormal (heterotopic) position will acquire a system of peripheral nerves derived from that part of the central nervous system of the host which corresponds to the position of the implanted limb rudiment. That such nerves may be partially functional has been shown both by slight spontaneous movements of the limbs and by movements in response to electrical stimulation.

The majority of the experiments to which reference has just been made were carried out upon anuran embryos at a period when the peripheral nerve paths were in part or wholly laid down. Accordingly, the limb rudiments were placed in the direct pathway of one or more developing spinal nerves which merely continued their growth into the rudiment so placed. In all of these experiments the transplanted limb was developed from an additional rudiment, taken from another embryo, the normal limb rudiments of the host being left intact.

Experiments carried out by the author upon the urodele, Amblystoma punctatum, in which the anterior limb rudiment was transplanted to an abnormal position at a period prior to initial outgrowth of the spinal nerves, strongly suggest that the limb exerts a guiding influence upon the segmental nerve supply and determines the path taken by the spinal nerves effecting its innervation. The positive reaction towards this influence appears to be greater in the nerves developing from the normal limb level of the cord than in those developing from more posterior segments of the cord.

Positive evidence has also been found to show that the functional activity of the transplanted limb has initiated a hyperplasia of the peripheral afferent neurones, the spinal ganglia connected with the heterotopic limb being considerably larger than their counterparts which do not supply an homologous organ. Evidence that the ganglionic hypertrophy has been brought about by an actual hyperplasia of the elements has been obtained by making a count of the ganglion cells.

Although diligent search has been made, no evidence has as yet been obtained to show that the functional activity of the transplanted limb has effected a hyperplasia of the peripheral somatic motor neurones, there being no constant differences in size between the motor horn areas supplying the heterotopic limb and the opposite side where the limb is not present.

The experiments were carried out upon embryos in the so-called tail bud stage (stage 29). In the majority of the experiments the anterior limb rudiment was excised and re-implanted in the same embryo at distances ranging from one to seven segments posterior to the normal position (autoplastic transplantation). Other experiments consisted of transplanting an additional anterior limb rudiment to an embryo in which the normal limb rudiments were left intact (homoplastic transplantations). The larvae were preserved at intervals from thirty to eighty days after the operation, the majority of cases being under observation for about sixty days.

The results of the transplantations are presented in table 1. The figures in table 1 A illustrate the significant fact, that, as the limbs are implanted farther and farther away from the normal situation, there occurs a corresponding decrease in their ability to function until a position is reached (six segments posterior to the normal, series AS6) in which all exhibit very imperfect movements, there being no cases with perfect adaptive function.

Additional anterior limbs transplanted successively three, four and five segments posterior to the normal intact limb of the host (table 1 B), while exhibiting slight twitching movements in cases, never attain the completeness of function reached by autoplastic limbs implanted in the same relative position.

The gradual decrease in the function of the autoplastic limbs as they are implanted more and more remote from the normal limb region seems to be directly correlated with the segmental nerve contribution (table 2).

The normal anterior limb is supplied by a plexus composed of the third, fourth and fifth spinal nerves (fig. 1). In the tail bud stage of embryonic development the anterior limb rudiment constitutes a slightly thickened region of somatopleural mesoderm lying just ventral to the pronephros and extending from the anterior border of the third somite to the posterior border of the fifth.

TABLE 1

A. Showing the results of transplanting the right anterior limb rudiment a number of segments (AS1, AS2, AS3, etc.) posterior to its normal position.

B. Showing the results of transplanting an additional anterior limb rudiment to an embryo in which the normal limb rudiments have been left intact. HS3, HS4 and HS5 indicate the successive number of segments the additional limb rudiment was implanted posterior to the normal right anterior limb of the host.

	SERIES	OPERATIONS	POSITIVE EXPERIMENTS	NORMAL LIMBS		REDUPLICATIONS		FUNCTIONAL LIMBS		NO FUNCTION		FUNCTION IMPAIRED		FUNCTION PERFECT	
				Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent	Cases	Per cent
A	AS1	25	20	19	95	1	5	20	100	0	0	1	5	19	95
	AS2	21	18	17	94.5	1	5.5	17	100	0	0	3	16.7	15	83.3
	AS3	24	17	13	76.5	4	23.5	15	88.2	2	11.8	4	23.5	11	64.7
	AS4	34	29	18	67.0	11	33	23	79.3	6	20.7	11	37.9	12	41.4
	AS5	35	30	11	36.7	19	63.3	20	66.7	10	33.3	16	53.3	4	13.4
	AS6	35	29	22	75.9	7	24.1	15	51.7	14	48.3	15	51.7	0	0
B	HS3	10	9	2	22.2	7	77.8	9	100	0	0	6	66.7	3	33.3
	HS4	30	21	8	38.1	13	61.9	11	52.4	10	47.6	11	52.4	0	0
	HS5	30	25	11	44.0	14	56.0	13	52.0	12	48.0	13	52.0	0	0

TABLE 2

Showing the segmental nerve contribution to the anterior limb when implanted successively a number of segments (1 to 7) posterior to its normal position.

SERIES	CASE	POSITION OF LIMB NUMBER OF SEGMENTS POSTERIOR TO NORMAL	SEGMENTAL NERVE CONTRIBUTION								
			3	4	5	6	7	8	9	10	11
Normal	1	0	3	4	5						
AS1	12	1	3	4	5						
AS2	5	2	3	4	5						
AS2	12	2	3	4	5						
AS3	9	3		4	5	6					
AS3	18	3		4	5	6					
AS4	12	4		4	5	6	7				
AS4	27	4				6	7	8			
AS4	26	4			5	6	7				
AS4	30	4			5	6	7				
AS5	25	5			5	6	7	8	9		
AS5	27	5				6	7	8	9		
AS5	23	5					7	8	9		
AS5	30	5				6	7	8	9		
AS5	26	5					7	8	9		
AS6	29	6						9	9	10	
AS6	5	6							9	10	
AS7	5	7								10	11

The outgrowing third, fourth and fifth spinal nerves in Amblystoma, effecting connection with the limb rudiment at a period when it occupies its maximum extent (anterior border of the third somite to the posterior border of the fifth), become converged into a plexus as a result of concentration of the rudiment into the definitive limb bud which centers under the fourth myotome. Such convergence having taken place, a typical normal plexus as illustrated in figure 1 is produced.

However, in the examination of the segmental nerve supply to the anterior limb when transplanted posteriorly through distances ranging from one to seven segments, it is found that limbs so placed receive the bulk of their nerve components from spinal segments situated anterior to the implanted limb rudiment rather than from segments corresponding to the new position of the limb (table 2 and fig. 2).

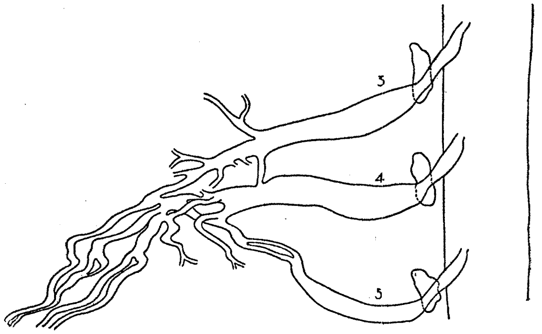

FIG. 1. GRAPHIC RECONSTRUCTION OF THE NORMAL LEFT BRACHIAL PLEXUS OF CASE AS4^{26}, PRESERVED SIXTY-EIGHT DAYS AFTER THE OPERATION. × 20

As has been observed previously, a very significant feature of table 2 illustrates the tendency of the transplanted limbs to be innervated by the nerves developing from the normal limb level of the cord, this tendency being most marked in the fourth and fifth nerves both of which, in the cases studied, were found to elongate in a postero-lateral direction a greater distance to effect innervation than did the third nerve or those developing from segments of the cord posterior to the normal limb level.

Anterior limbs when implanted the distance of one or two segments posterior to the normal position receive the normal segmental nerve contribution (table 2, series AS1 and AS2). The function of such limbs is practically as complete as that of the limbs in their normal position. When transplanted posteriorly the distance of three segments, the third spinal nerve no longer contributes to the innervation of the limb and the function of limbs in this position is less complete (table 2, series AS3).

When transplanted posteriorly the distance of four segments, all cases studied, with one exception, show that the fourth spinal nerve no longer contributes to the innervation of the limb and that limbs in this position exhibit still greater imperfection of function (table 2, series AS4).

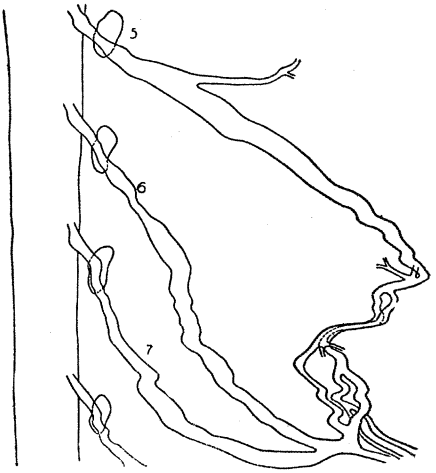

FIG. 2. GRAPHIC RECONSTRUCTION OF THE RIGHT BRACHIAL PLEXUS OF CASE AS4^{26}, SHOWING THE SEGMENTAL NERVE SUPPLY TO THE RIGHT ANTERIOR LIMB TRANSPLANTED THE DISTANCE OF 4 SEGMENTS POSTERIOR TO THE NORMAL POSITION. × 20

In the series AS5 in which the limbs were implanted the distance of five segments posterior to the normal position, there occurred only one case of those studied (case AS5^{25}, table 2) in which the limb received innervation from the fifth spinal nerve, the remainder being innervated by nerves posterior to the normal brachial nerves. With this general failure of the limbs in this position to receive innervation from the normal brachial nerves, it is found that still greater restrictions are placed upon their movements, there being only four cases in thirty which functioned normally (table 1 A).

In the series AS6 in which the limbs are so far removed that they receive no contribution from the normal limb nerves nor from the sixth and seventh nerves, there are no cases which function normally, forty eight per cent being totally incapable of movements and fifty one per cent showing only greatly impaired movements (table 1 A and table 2).

Inasmuch as there are practically no structural deficiencies within the transplanted limb itself, the gradual decrease in the function of the limbs, as they are implanted more and more remote from the normal region, suggests the following possible factors as conditioning their degree of function, (a) structural deficiencies in the shoulder girdle, (b) deficiencies in the shoulder musculature, (c) the failure of certain of the shoulder muscles to receive innervation and (d) the absence of proper central neurone connections.

The shoulder girdle being a mosaic (Detwiler[5]), there is considerable variability in the degree of its development in the transplanted position, yet it is found that its development, in general, is no less complete in cases where the limb has been removed a considerable distance from the normal region than in those where the limb has been removed only a short distance. The difference, therefore, in the degree of function of the limbs could hardly be a result of this factor alone. Secondly, a study of the cross section anatomy of the shoulder region of the transplanted limbs shows that shoulder muscle differentiation does not become less complete as the limbs are implanted more and more posteriorly. No cases have been found in which there was complete absence of any of the muscles which typically develop in the heterotopic position.

Thirdly, peripheral efferent innervation to the shoulder muscles, although somewhat less complete quantitatively in the more posterior positions than in cases where the transplanted limb receives segmental nerves from all or a part of the normal limb level of the cord, is no less developed qualitatively, practically all of the individual muscles receiving some nerve fibers. Certainly the degree of defective peripheral innervation could hardly account entirely for the very imperfect movements exhibited by limbs in the series AS5 and AS6 (table 1 A).

The remaining factor viz: defective connections within the central nervous system appears to be the only one which will adequately account for the marked deficiency of function in limbs transplanted so far posteriorly as to be beyond the point where they receive peripheral innervation from the normal limb level of the cord.

Although in normal larvae of this age, the most obvious motor responses to various types of peripheral stimulation consist of total swimming reactions, under certain controlled conditions motor responses may be almost entirely limited to co-ordinated movements of the limbs. Such responses may be carried out perfectly by the transplanted limbs when their peripheral innervation is derived from the normal limb level of the cord, but the ability of the transplanted limbs to exhibit movements, co-ordinated with the opposite intact limb, decreases markedly when their peripheral innervation is derived from segments well beyond the normal limb level (series AS6).

As has been shown by Herrick[6] we have developed here a central nervous architecture by means of which peripheral sensory stimuli pass through more or less localized ascending sensory tracts from the cord to the medulla (tractus spino-bulbaris), to the midbrain (tractus spino-tectalis) and to the thalmus (tractus spino-thalamicus). These stimuli may become finally discharged into the somatic motor centers of the spinal cord by means of descending tracts such as the tractus thalamo-bulbaris, tractus tecto-bulbaris, the fasciculus longitudinalis medialis and the tractus bulbo-spinalis. According to Herrick the cell bodies of the tractus bulbo-spinalis lie in the general motor tegementum of the medulla and their axones are directed ventrally into the ventral funiculi of the same and the opposite side. It is highly probable that a certain number of these fibers normally develop only as far as the third, fourth and fifth segments of the cord for specific discharge into the normal appendicular somatic motor centers. The fact that transplanted limbs, receiving peripheral innervation from these levels, exhibit movements which are co-ordinated with the opposite intact limb, strongly suggest such a condition. The behavior of limbs innervated mainly from the sixth, seventh and eighth segments of the cord (series AS5) suggests that these descending neurones, which normally end in the limb level, may be induced to continue their growth an additional segment or two to meet the functional demands imposed upon them by the transplanted limb. Their incapacity for further functional regulation is suggested by the loss of co-ordinated function and the greatly impaired movements that are exhibited by limbs of the series AS6, probably none of which receive peripheral innervation from segments of the cord anterior to the eighth.

The increase in the number of cases with total loss of function as the limbs are implanted more and more posteriorly (table 1 A) would also suggest that there occurs a corresponding increased deficiency in the connections of the purely intraspinal correlation neurones.

Additional limbs transplanted respectively three, four and five segments posterior to the normal intact limb of the host (table 1 B), never attain the completeness of function attained by limbs in the same relative positions with the normal limb extirpated. Although such limbs may be well supplied with peripheral nerves, derived from segments of the cord posterior to the normal limb level, their greatly impaired movements appear to be a consequence of their inadequate supply of central efferent neurones, which run apparently only as far as the normal limb level where they discharge into the somatic motor centers of the normal intact limb.

The generally restricted and non-adaptive movements which these limbs do exhibit upon stimulation are probably effected through more or less imperfectly connected intraspinal, intersegmental correlation neurones of the levels from which peripheral innervation is derived.

A more complete account of the experiments reported in this paper will appear in later publications.

[1] Braus, H., *Morph. Jahrb.*, **35**, 1906.
[2] Banchi, A., *Anat. Anz.*, **28**, 1906.
[3] Gemelli, F. A., *Rev. Pathologia Nervosa Mentale*, **11**, 1906.
[4] Harrison, R. G., *J. Exp. Zool.*, **4**, 1907.
[5] Detwiler, S. R., *Ibid.*, **4**, 1918.
[6] Herrick, C. J., *J. Comp. Neur.*, **24**, 1914.

THE INTERFEROMETRY OF RAPID VIBRATIONS[1] CHIEFLY IN RELATION TO TELEPHONE CURRENTS

By C. Barus

Department of Physics, Brown University

Communicated June 13, 1919

1. Introductory.—The preceding apparatus[2] with telescopic or microscopic enlargement of the telephonic vibrations, behaved on the whole so satisfactorily, that it seemed worth while to try a similar design on the interferometer. I was inclined to doubt the feasibility of the plan; but it appeared on trial that the high tension wires actually keep the auxiliary mirrors of the interferometer practically quiet; so that in the absence of alternating current it is not difficult to find the fringes. Tense wires are out of step with the usual laboratory tremors. The system needs no special damping.

The displacement of achromatic fringes due to the induced secondary current is normal to their direction. The objective of the vibration telescope is to oscillate in the direction of the fringes and to